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## The Brightest Serendipitous X-ray Sources in ChaMPlane

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**Abstract.** The *Chandra* Multiwavelength Plane (ChaMPlane) Survey is a comprehensive effort to constrain the population of accretion-powered and coronal low-luminosity X-ray sources ( $L_X \lesssim 10^{33} \text{ erg s}^{-1}$ ) in the Galaxy. ChaMPlane incorporates X-ray, optical, and infrared observations of fields in the Galactic Plane imaged with *Chandra* in the past six years. We present the results of a population study of the brightest X-ray sources in ChaMPlane. We use X-ray spectral fitting, X-ray lightcurve analysis, and optical photometry of candidate counterparts to determine the properties of 21 sources. Our sample includes a previously unreported quiescent low-mass X-ray binary or cataclysmic variable ( $R = 20.9$ ) and ten stellar sources ( $12.5 \lesssim R \lesssim 15$ ), including one flare star ( $R = 17.3$ ). We find that quantile analysis, a new technique developed for constraining the X-ray spectral properties of low-count sources, is largely consistent with spectral fitting.

### 1. Introduction

Accretion powered binaries with compact objects include white dwarfs in cataclysmic variables (CVs) and neutron stars/black holes in quiescent low-mass X-ray binaries (qLMXBs). Space densities of CVs and qLMXBs are poorly constrained physical quantities due to small number statistics and systematic selection effects (Warner 1995). The *Chandra* Multiwavelength Plane (ChaMPlane) Survey aims to constrain the Galactic population of low-luminosity ( $L_X \lesssim 10^{33} \text{ erg s}^{-1}$ ) accretion-powered X-ray binaries using serendipitous sources detected in six years of deep ( $\gtrsim 20$  ks) *Chandra* observations. The current database includes  $\sim 15000$  X-ray sources from 122 fields. ChaMPlane will use *Chandra*'s sensitivity to detect CVs and qLMXBs beyond  $\sim 1.2$  kpc, the approximate limit of previous surveys; this future sample will allow us to study the spatial and luminosity distributions of CVs and qLMXBs on Galactic scales.

ChaMPlane utilizes deep optical imaging (to  $R = 24$ ) to identify candidate source counterparts for follow-up studies. Each of the 122 *Chandra* fields is imaged in *VRI* and  $H\alpha$  with the Mosaic cameras on the KPNO- and CTIO-4m telescopes. Ongoing efforts for complete source classification include optical spectroscopy and infrared imaging of heavily reddened Galactic Bulge regions. A second major goal of ChaMPlane is to study populations of stellar coronal sources. By combining observations of coronal sources with spectral identifica-

tions from ChaMPlane's optical survey, we will be able to constrain when stars develop coronae.

In this study, we determine the properties of the brightest serendipitous sources using X-ray spectral fitting, X-ray lightcurve analysis, and optical photometry of candidate counterparts (§2.). We also test the predictions of quantile analysis for the first time (§3.).

## 2. The bright sample

Grindlay et al. (2005) details the selection criteria for the entire ChaMPlane Survey. For this study, we apply further criteria, including a requirement that the number of net source counts in the broad ( $B_X$ ,  $.3 - 8$  keV) band  $\gtrsim 250$ , to confidently model and fit X-ray spectra. We exclude the inner Bulge ( $l > 358^\circ$  and  $l < 2^\circ$ ) to study a less crowded environment.

Our bright sample is composed of 21 serendipitous X-ray sources. Ten have candidate optical counterparts with  $R \lesssim 24$ ; five of these have optical spectra in our current spectral database. Optical counterpart matching is in progress for three remaining sources.

### 2.1. The CV/qLMXB candidate

One X-ray source is well fit (reduced  $\chi^2 = .94$ ) by the absorbed powerlaw model, with  $\Gamma = 1.01^{+.14}_{-.13}$  and  $N_H = .22^{+.12}_{-.11} \times 10^{22}$  cm $^{-2}$ . The unabsorbed flux in  $B_X$  is  $5.1 \pm 1.2 \times 10^{-13}$  erg cm $^{-2}$  s $^{-1}$ . Assuming the Galactic dust distribution of Drimmel & Spergel (2001), the  $N_H$  implies a distance of 1.3 kpc. The unabsorbed luminosity in  $B_X$  is thus  $10^{32}$  erg s $^{-1}$ , consistent with luminosities of both qLMXBs and CVs. The X-ray lightcurve (Fig. 1) appears periodic; it deviates from a constant count rate to 1% significance. Furthermore, the candidate optical counterpart of this source has a large H $\alpha$  excess ( $H\alpha - R = -.48 \pm .13$ ) and is bluer than many objects in the surrounding field. The ratio of unabsorbed X-ray flux to unabsorbed  $R$  flux (i.e., unabsorbed  $F_X/F_R$ ) is 28.3; for comparison, most stellar coronal sources have unabsorbed  $F_X/F_R \sim 10^{-3}$ . This source is most likely a CV or qLMXB. Further work will help determine the precise nature of the compact object.

### 2.2. The remaining sample

Combining X-ray spectral fits with candidate optical counterpart photometry and spectroscopy in the same way as in §2.1., we characterize the remainder of our sample. Our preliminary results indicate the sample consists of the CV/qLMXB candidate; ten stellar sources, one of which shows an X-ray flare during the *Chandra* observation; three probable active galactic nuclei (AGN); one candidate young stellar object (YSO); and six unclassified sources. These six include four sources with optical counterparts too faint for ChaMPlane; if we assume a limiting absorbed  $R \simeq 24$ , two of these four sources have unabsorbed  $F_X/F_R > 1$ , values too high for the sources to be stellar coronae. Unabsorbed  $F_X/F_R$  for the sample is shown in Fig. 2; the ratios range from  $\sim 10^{-3}$  for stellar coronal sources to  $\simeq 30$  for the CV/qLMXB candidate.

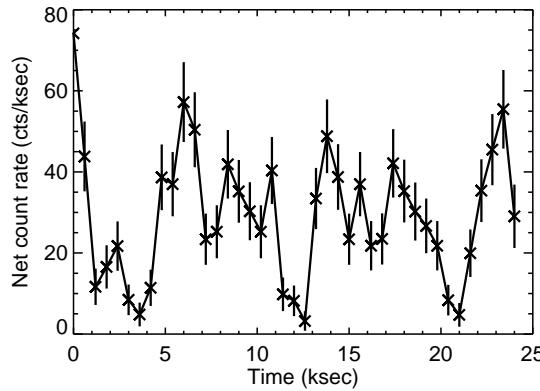


Figure 1. Background subtracted X-ray lightcurve for the CV/qLMXB candidate, binned in 600 second intervals. A K-S test on the photon arrival times shows a significant ( $p = .009$ ) departure from a constant count rate.

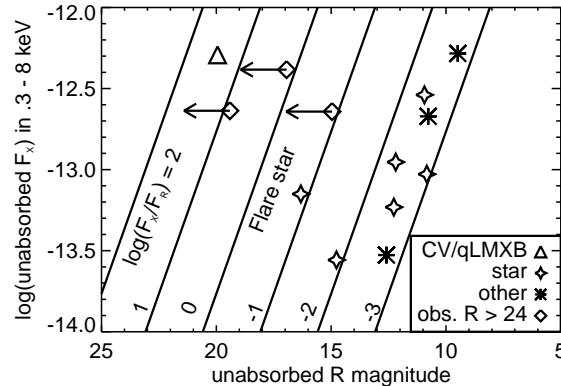


Figure 2. Unabsorbed X-ray flux against unabsorbed  $R$  magnitude for the sample. Also shown are lines of constant  $\log(F_X/F_R)$ . Several X-ray sources have spectra fit well using multiple models; only models with a strictly optimal reduced  $\chi^2$  are plotted. Sources for which the optical counterpart is too faint are shown with upper limits to the unabsorbed  $R$  magnitude.

### 3. Quantile analysis

Most X-ray sources in ChaMPlane's catalog do not have enough counts for confident spectral fitting. Quantile analysis, detailed in Hong et al. (2004), is a method of constraining the absorption and spectral parameters of low-count sources (see Fig. 3). We perform quantile analysis for the 21 bright sources using both powerlaw and thermal bremsstrahlung models. For the first time, we test the predictions of quantile analysis against spectral parameters from fitting. We find that, of the 13 sources where the X-ray spectrum is best fit by either a

powerlaw or thermal bremsstrahlung model, only 2 have quantile values outside the  $1\sigma$  results from spectral fitting. All sources have quantile values within the  $2\sigma$  results from spectral fitting.

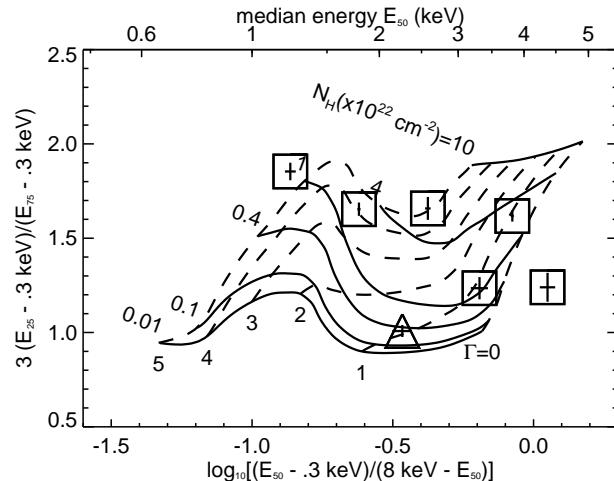


Figure 3. Quantile color-color diagram (QCCD) for the absorbed powerlaw model. Soft, unobscured sources are to the bottom-left, and hard, obscured sources are to the top-right; spectral parameters (here,  $\Gamma$ ) and  $N_H$  are constrained by comparison with model grids. Plotted on this diagram are a few sources from our bright sample; the CV/qLMXB candidate is marked with a triangle.  $E_{50}$  is the median energy;  $E_{25}$  and  $E_{75}$  are the quartile energies.

#### 4. Conclusions

Our population study of the brightest serendipitous X-ray sources in the ChaM-Plane Survey has uncovered a previously unreported CV/qLMXB, ten stellar sources (including a flare star), three possible AGN, and one candidate YSO.

We perform quantile analysis on our sample and find that it predicts spectral parameters and absorption mostly to within the  $1\sigma$  errors of X-ray spectral fitting.

We plan to further study the CV/qLMXB candidate and determine more properties (e.g. spectral types of stellar objects) of our bright X-ray sample.

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